In the case of the conventional catadioptric systems, adjustment was difficult because of eccentricity of optical axis, and thus, image-forming performance as designed was rarely able to be achieved. In contrast, the catadioptric projection optical system according to the present invention permits independent adjustment of the first image-forming optical system and the second image-forming optical system, and after the adjustment the two image-forming optical systems may be set with the optical axis approximately vertical, which facilitates adjustment of eccentricity etc.

Since the image magnification by the first image-forming optical system can be freely selected, an excellent optical performance state can be realized.

In this case, an advantage of a further size reduction of the beam splitter can be attained by forming the intermediate image inside the prism type beam splitter.

Next, because the second catadioptric projection optical system of FIG. 17 is so arranged that the image is once formed between the concave, reflective mirror and the second plane (image plane), there are advantages that a compact partial mirror can be used and that the optical path between the concave, reflective mirror and the image plane can be set long. Further, when the partial mirror is used, the best image region is, for example, arcuate or slit as eccentric from the optical axis. Such an image region is suitable for the projection exposure apparatus of the scanning exposure method.

Next, when the conditions of equations (1) to (3) are satisfied, the Petzval sum of the total optical system readily becomes nearly 0, so that the projection image surface becomes approximately flat. Further, when the conditions of equations (4) and (5) are satisfied, a magnification balance becomes reasonable, and the optical system can be easily constructed.

From the invention thus described, it will be obvious that the invention may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims. The basic Japanese Application No. 6-90837 filed on Apr. 28, 1994 is hereby incorporated by reference.

What is claimed is:

1. A catadioptric projection optical system for projecting an image of a pattern of a first surface onto a second surface, said catadioptric projection optical system comprising:

a first image-forming optical system for forming an intermediate image of the pattern of said first surface, said first image-forming optical system including:

a first group with a positive refractive power, comprising a refractive lens component, for converging a light beam from the pattern of said first surface,

a second group with a positive refractive power, comprising a concave, reflective mirror for reflecting a light beam from said first group, for forming said intermediate image of the pattern of said first surface, and

a beam splitting optical system for changing a traveling direction of one of a light beam from said first group and a reflected light beam from said concave, reflective mirror; and

a second image-forming optical system for forming an image of said intermediate image on said second surface.

2. A catadioptric projection optical system according to claim 1, wherein said beam splitting optical system is

defined as a beam splitter of which a beam splitter surface is arranged obliquely to an optical axis of said first group, said beam splitter disposed on the optical axis of said first group and provided on the optical path between said concave, reflective mirror and said second image-forming optical system.

3. A catadioptric projection optical system according to claim 1, wherein

said beam splitting optical system is defined as a partial mirror of which a first reflective surface is arranged obliquely to an optical axis of said first group, said partial mirror provided between said first group and said second group so as to avoid being disposed on the optical axis of said first group, and wherein

the light beam converged by said second group is guided to said second image-forming optical system by a second reflective surface of said partial mirror, said second reflective surface being opposite to said first reflective surface of said partial mirror.

4. A catadioptric projection optical system according to claim 2, wherein

said beam splitter is a prism-type shaped.

5. A catadioptric projection optical system according to claim 4, wherein

said beam splitter is one of a polarizing beam splitter and a partially-reflective beam splitter.

√ 6. A catadioptric projection optical system for projecting an image of a pattern of a first surface onto a second surface, comprising a first image-forming optical system for forming an intermediate image of the pattern of said first surface, and a second image-forming optical system for forming an image of said intermediate image on said second surface, wherein said first image-forming optical system includes

a first group with a positive refractive power, comprising a refractive lens component, for converging a light beam from the pattern of said first surface,

a beam splitter for separating a part of a light beam from said first group by a beam-splitter surface arranged obliquely to an optical axis of said first group, said beam splitter disposed on the optical axis of said first group; and

a second group with a positive refractive power, comprising a concave, reflective mirror for reflecting the light beam separated by said beam splitter, for forming said intermediate image of the pattern between the concave, reflective mirror and the second image-forming optical system, said beam splitter provided between said concave, reflective mirror and said second image-forming optical system.

7. A catadioptric projection optical system according to claim 6, wherein

said beam splitter is a prism-type shaped, and said intermediate image of the pattern of said first surface is formed inside said beam splitter.

8. A catadioptric projection optical system according to claim 6, wherein

the following conditions are satisfied:

$$p_1+p_2<0,\ p_3>0,\ \text{and}\ |p_1+p_2+p_3|<0.1,$$

where p_1, p_2, and p_3 are individual Petzval's sums of said first group, second group, and second image-forming optical system; and

wherein the following conditions are satisfied:

$$0.1<|\beta_{12}|<0.5\ \text{and}\ 0.25<|\beta_3|<2.$$

where β_{12} is a magnification of from the pattern on said first surface to said intermediate image and β_3 is a magnification of from said intermediate image to said image on the second surface.

9. A catadioptric projection optical system according to claim 7, wherein

said beam splitter is one of a polarizing beam splitter and a partially-reflective beam splitter.

10. A catadioptric projection optical system for projecting an image of a pattern of a first surface onto a second surface, comprising a first image-forming optical system for forming an intermediate image of the pattern of said first surface, and a second image-forming optical system for forming an image of said intermediate image on said second surface, wherein said first image-forming optical system includes:

a first group with a positive refractive power, comprising a refractive lens component, for converging a light beam from the pattern of said first surface;

a partial mirror for separating a part of alight beam from said first group by a first reflective surface arranged obliquely to an optical axis of said first group, said partial mirror-positioned so as to avoid being disposed on the optical axis of said first group; and

a second group of a positive refractive power, comprising a concave, reflective mirror for reflecting the light beam of which the part is separated by said first reflective surface of said partial mirror, for forming said intermediate image of the pattern between said concave, reflective mirror and said second image-forming optical system, said partial mirror provided between said first group and said second group,

wherein the light beam converged by said second group is guided to said second image-forming optical system by a second reflective surface of said partial mirror, said second reflective surface being opposite to said first reflective surface of said partial mirror.

11. A catadioptric projection optical system according to claim 10, wherein

the following conditions are satisfied:

$$p_1+p_2<0,\ p_3>0,\ \text{and}\ |p_1+p_2+p_3|<0.1,$$

where p_1, p_2, and p_3 are individual Petzval's sums of said first group, second group, and second image-forming optical system; and

wherein the following conditions are satisfied:

$$0.1<|\beta_{12}|<0.5\ \text{and}\ 0.25<|\beta_3|<2,$$

where β_{12} is a magnification of from the pattern on said first surface to said intermediate image and β_3 is a magnification of from said intermediate image to said image on the second surface.

12. An exposure apparatus comprising:

a stage allowing a photosensitive substrate to be held on a main surface thereof;

an illumination optical system for emitting exposure light of a predetermined wavelength and transferring a predetermined pattern of a mask onto said substrate; and

a catadioptric projection optical system provided between a surface on which the mask is disposed and said substrate, for projecting an image of the pattern of said mask onto said substrate, said catadioptric projection optical system including:

a first image-forming optical system for forming an intermediate image of the pattern of said mask, said first image-forming optical system having

a first group with a positive refractive power, comprising a refractive lens component, for converging a light beam from the pattern of said mask,

a second group with a positive refractive power, comprising a concave, reflective mirror for reflecting a light beam from said first group, for forming said intermediate image of the pattern of said mask; and

a beam splitting optical system for changing a traveling direction of one of a light beam from said first group and a reflected light from said concave, reflective mirror; and

a second image-forming optical system for forming an image of said intermediate image on said substrate.

13. An exposure apparatus according to claim **12**, wherein said beam splitting optical system is defined as a beam splitter of which a beam splitter surface is arranged obliquely to an optical axis of said first group, said beam splitter disposed on the optical axis of said first group and provided on the optical path between said concave, reflective mirror and said second image-forming optical system.

14. An exposure apparatus according to claim **12**, wherein said beam splitting optical system is defined as a partial mirror of which a first reflective surface is arranged obliquely to an optical axis of said first group, said partial mirror provided between said first group and said second group so as to avoid being disposed on the optical axis of said first group, and wherein

the light beam converged by said second group is guided to said second image-forming optical system by a second reflective surface of said partial mirror, said second reflective surface being opposite to said first reflective surface of said partial mirror.

15. An exposure apparatus according to claim **13**, wherein said beam splitter is a prism-type shaped.

16. An exposure apparatus according to claim **15**, wherein said beam splitter is one of a polarizing beam splitter and a partially-reflective beam splitter.

17. An exposure apparatus comprising:

a stage allowing a photosensitive substrate to be held on a main surface thereof;

an illumination optical system for emitting exposure light of a predetermined wavelength and transferring a predetermined pattern of a mask onto the substrate; and

a catadioptric projection optical system provided between a surface on which said mask is disposed and said substrate, for projecting an image of the pattern of said mask onto said substrate, comprising a first image-forming optical system for forming an intermediate image of the pattern of said mask, and a second image-forming optical system for forming an image of said intermediate image on said substrate, wherein said first image-forming optical system includes:

a first group with a positive refractive power, comprising a refractive lens component, for converging a light beam from the pattern of said mask,

a beam splitter for separating a part of alight beam from said first group by a beam-splitter surface arranged obliquely to an optical axis of said first group, said beam splitter disposed on the optical axis of said first group; and

a second group with a positive refractive power, comprising a concave, reflective mirror for reflecting the light beam separated by said beam splitter, for form-

ing said intermediate image of the pattern between the concave. reflective mirror and the second image--forming optical system. said beam sputter provided between said concave. reflective mirror and said second image-forming optical system

18. An exposure apparatus according to claim **17**. wherein said beam splitter is a prism-type shaped. and said intermediate image of the pattern of said first surface is formed inside said beam splitter.

19. An exposure apparatus according to claim **17**. wherein the following conditions are satisfied:

$$p_1+p_2<0,\ p_3>0,\ \text{and}\ |p_1+p_2+p_3|<0.1,$$

where p_1, p_2, and p_3 are individual Petzval's sums of said first group. second group. and second image-forming optical system; and

wherein the following conditions are satisfied:

$$0.1<|\beta_{12}|<0.5\ \text{and}\ 0.25<|\beta_3|<2,$$

where β_{12} is a magnification of from the pattern on said first surface to said intermediate image and β_3 is a magnification of from said intermediate image to said image on the second surface.

20. An exposure apparatus according to claim **18**. wherein said beam sputter is one of a polarizing beam splitter and a partially-reflective beam splitter.

21. An exposure apparatus comprising:

a stage allowing a photosensitive substrate to be held on a main surface thereof;

an illumination optical system for emitting exposure light of a predetermined wavelength and transferring a predetermined pattern of a mask onto the substrate; and

a catadioptric projection optical system provided between a surface on which said mask is disposed and said substrate. for projecting an image of the pattern of said mask onto said substrate. comprising a first image-forming optical system for forming an intermediate image of the pattern of said mask. and a second image-forming optical system for forming an image of said intermediate image on said substrate. wherein said first image-forming optical system includes:

a first group with a positive refractive power. comprising a refractive lens component. for converging a light beam from the pattern of said mask;

a partial mirror for separating a part of a light beam from said first group by a first reflective surface arranged obliquely to an optical axis of said first group. said partial mirror positioned so as to avoid being disposed on the optical axis of said first group; and

a second group of a positive refractive power. comprising a concave. reflective mirror for reflecting the light beam of which the part is separated by said first reflective surface of said partial mirror. for forming said intermediate image of the pattern between said concave. reflective mirror and said second image-forming optical system. said partial mirror provided between said first group and said second group.

wherein the light beam converged by said second group is guided to said second image-forming optical system by a second reflective surface of said partial mirror. said second reflective surface being opposite to said first reflective surface of said partial mirror.

22. An exposare apparatus according to claim **21**. wherein the following conditions are satisfied:

$$p_1+p_3>0,\ p_2<0,\ \text{and}\ |p_1+p_2+p_3|<0.1,$$

where P_1, p_2, and p_3 are individual Petzval's sums of said first group, second group, and second image-forming optical system; and

wherein the following conditions are satisfied:

$$0.1<|\beta_{12}|<0.5\ \text{and}\ 0.25<|\beta_3|<2,$$

where β_{12} is a magnification of from the pattern on said first surface to said intermediate image and β_3 is a magnification of from said intermediate image to said image on the second surface.

23. A catadioptric projection optical system for projecting an image of a pattern of a first surface onto a second surface, said catadioptric projection optical system comprising a first image-forming optical system, a second image-forming optical system, and a partial mirror, wherein

said first image-forming optical system includes:

a first group with a positive refractive power, said first group comprising a refractive lens component; and

a second group with a [negative] <u>positive</u> refractive power, said second group comprising a concave, reflective mirror,

said second image-forming optical system includes a refractive lens component and an aperture stop,

light from said first surface passes through in order said first group, said second group, said partial mirror, and said second image-forming optical system and thereafter said light reaches said second surface,

said partial mirror is positioned so as to avoid disposing on an optical path of light that travels from said first group to said second group and is disposed on an optical path of light that travels from said second group to said second image-forming optical system, and

an intermediate image of said pattern of said first surface is formed at a predetermined position of said optical path of light that travels from said second group to said second image-forming optical system.

24. A catadioptric projection optical system according to claim **23**, wherein

the following conditions are satisfied:

$$p_1+p_3>0,\ p_2<0,\ \text{and}\ |p_1+p_2+p_3|<0.1,$$

where P_1, p_2, and p_3 are individual Petzval's sums of said first group, second group, and second image-forming optical system; and

wherein the following conditions are satisfied:

$$0.1<|\beta_{12}|<0.5\ \text{and}\ 0.25<|\beta_3|<2,$$

where β_{12} is a magnification of from the pattern on said first surface to said intermediate image and β_3 is a magnification of from said intermediate image to said image on the second surface.

25. A fabricating device method comprising:

preparing a mask with a predetermined pattern;

illuminating said mask with exposure light having a predetermined wavelength; and

projecting a secondary image of said pattern onto a photosensitive substrate through a catadioptric optical system according to claim **1**.

* * * * *

26. A catadioptric imaging optical system used in a projection exposure apparatus that transfers a pattern on a mask onto a substrate, comprising:

a first imaging optical sub-system arranged in an optical path between the mask and the substrate, said first imaging optical sub-system comprising

a first group with a lens, and

a second group with a concave mirror,

wherein said first imaging optical sub-system forms an intermediate image of the pattern;

a second imaging optical sub-system arranged in an optical path between said first imaging optical sub-system and the substrate, wherein said second imaging optical sub-system forms an image of the intermediate image on the substrate; and

an optical path deflecting member arranged between said first group and said second group of said first imaging optical sub-system, wherein said optical path deflecting member changes a direction of either a light beam from said first group or a light beam reflected by the concave mirror.

27. A catadioptric imaging optical system according to claim 26, wherein said second imaging sub-system comprises an optical axis along a straight line.

28. A catadioptric imaging optical system according to claim 27, wherein said first group has an optical axis, and wherein said optical path deflecting member comprises a beam splitter surface that is inclined with respect to the optical axis of said first group.

29. A catadioptric imaging optical system according to claim 28, wherein said optical path deflecting member comprises a prism-type beam splitter.

30. A catadioptric imaging optical system according to claim 27, wherein said first group has an optical axis, wherein said optical path deflecting member comprises a reflection member that is arranged at a region not including the optical axis of said first group, and wherein the reflection member comprises a reflection surface inclined with respect to the optical axis of said first group.

31. A catadioptric imaging optical system according to claim 27, wherein said first group has a positive refractive power and said second group has a positive power.

32. A catadioptric imaging optical system according to claim 26, wherein the following conditions are satisfied:

$p_1 + p_2 < 0$,

$|p_1 + p_2 + p_3| < 0.2$,

$0.1 < |\beta_{12}| < 0.5$, and

$0.25 < |\beta_3| < 2$,

where

p_1, p_2 and p_3 are individual Petzval's sums of said first group, said second group, and said second imaging optical system,

β_{12} is a magnification of an optical system positioned in an optical path from the mask to the intermediate image, and

β_3 is a magnification of an optical system positioned in an optical path from the intermediate image to the substrate.

33. A projection exposure apparatus that transfers a pattern on a mask onto a substrate, comprising:

a catadioptric imaging optical system according to claim 26, wherein said catadioptric imaging optical system forms an exposure region at a position out of an optical axis of said second imaging sub-system.

34. A projection exposure apparatus according to claim 31, wherein the reticle and the substrate are scanned at different speeds corresponding to the magnification of said catadioptric imaging optical system.

35. A method of imaging a pattern on a mask onto a substrate, comprising:

guiding a light from the mask to a first group, wherein the first group comprises a lens;

guiding the light from the first group to a second group, wherein the second group comprises a concave mirror;

forming an intermediate image of the pattern based on the light from the second group;

guiding the light from the intermediate image to a dioptric imaging sub-system;

forming an image of the intermediate image on the substrate based on the light from the dioptric imaging sub-system; and

changing a direction of either the light beam from the first group or the light beam reflected by the concave mirror, in a space between the first group and the second group.